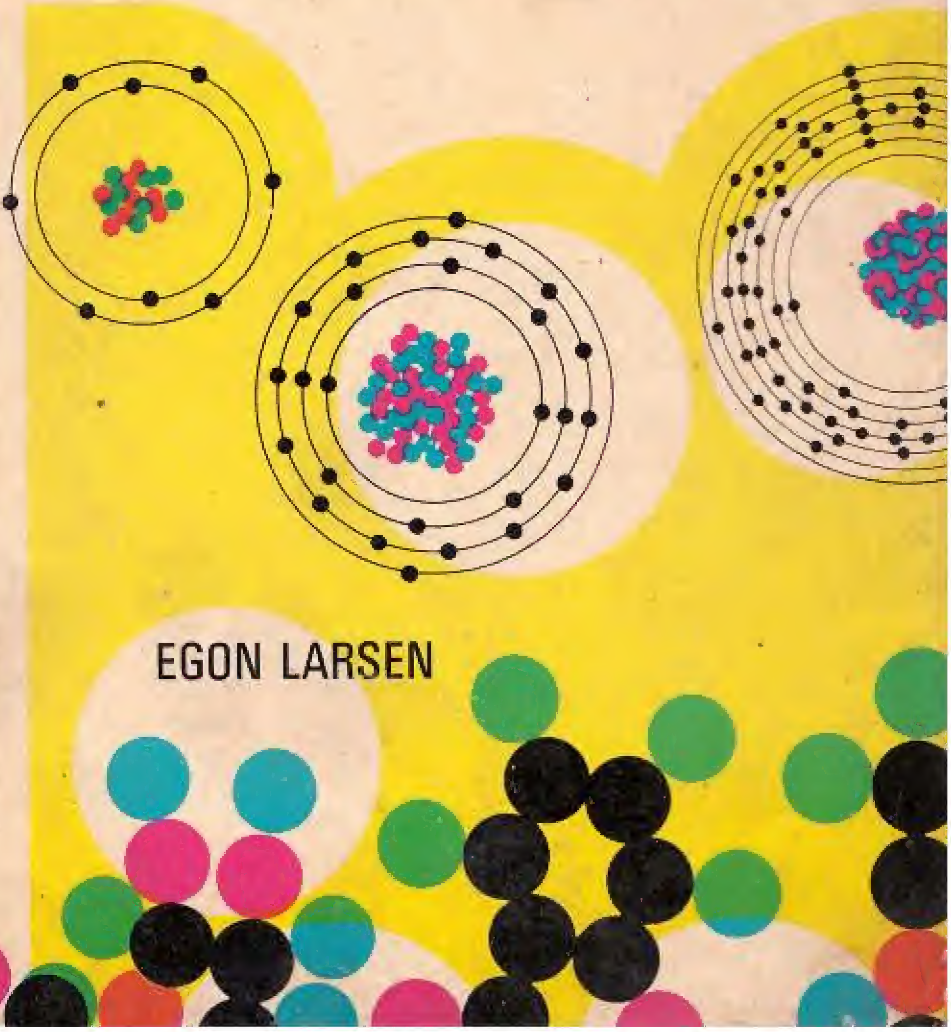
50 CENTS

Finding Out About **SCIENCE**

ATOMS

and Atomic Energy

The discovery of the atom and how men use atomic power



EGON LARSEN

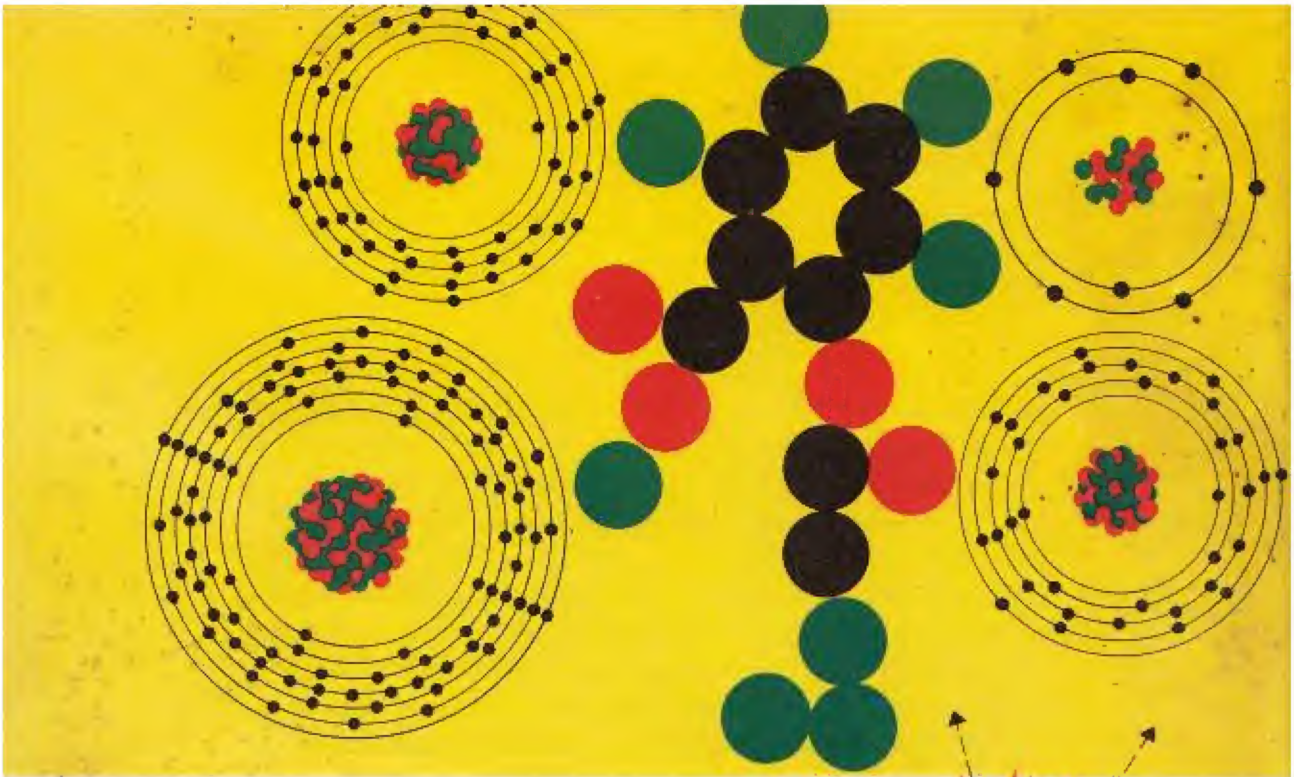
Atoms and Atomic Energy

We speak about the "atomic age", but what does it really mean? What is that mysterious source of power which is now serving us in so many different ways?

In this book, Egon Larsen tells the story of the discovery of the atom—a story which begins thousands of years ago in Greece —and how scientists little by little are uncovering the secrets of the smallest piece of matter. They had to work like detectives picking up clues here and there, and forming in their minds an idea of what the atom might look like—but they could never hope to see it with their own eyes. Famous men carried out innumerable experiments to find out whether these ideas were right or wrong.

And then, at last, science found a way by which the tremendous energy stored up in the atom could be put to use. Now we are beginning to use it. When we switch on an electric light, some of the current that makes the bulb shine may come from "smashed" atoms in a nuclear power station. Research in laboratories, automatic control in factories; these are only a few of the uses of atomic energy in our time.

This book will introduce the very young would-be scientist to an exciting field of modern knowledge.

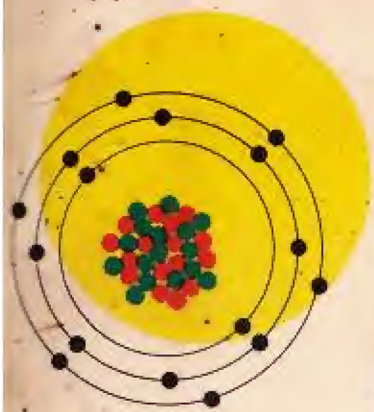


Finding Out

About SCIENCE

Edited by

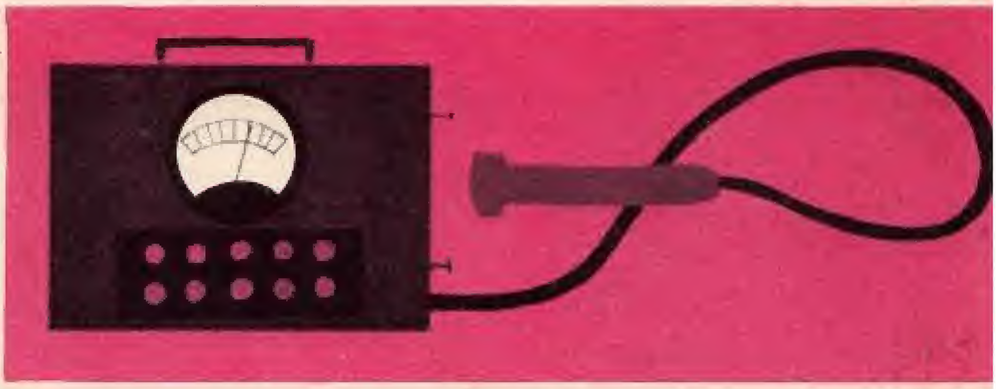
KURT ROWLAND



ATOMS AND ATOMIC ENERGY

By EGON LARSEN

Illustrated by BERNARD LODGE



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The photograph of Dalton's *Symbols of the Elements*, 1806-7, on page 13, is reproduced by courtesy of the Manchester Literary and Philosophical Society (Science Museum, London).

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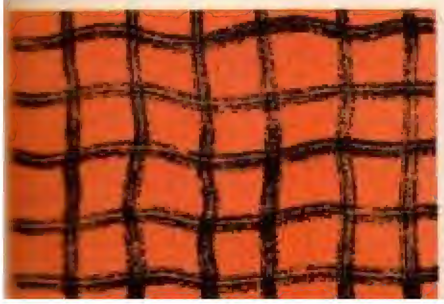
Contents

Have you ever wondered what all the things you see around you are made of? A house may be built of bricks, and a brick, as you can see if you look at it closely, is made up of little lumps of hardened clay, and each little lump is made up of still smaller ones. How small are the smallest lumps?

If you were to look closely at curtains such as those shown in the picture above, you would see the threads of which the material is made. They might look like those in the picture on the left below. If you looked at them under a microscope, you would probably see the fibers, as shown in the middle picture below.

Now if you had a really powerful microscope you would see that the fibers are made up of still smaller pieces. But where does it all end? Is there anything smaller still? What is this thing called *matter*, of which bricks, fabrics and everything else in our world is made?



The ancient Greeks liked to talk and argue about all kinds of things, such as nature, God, and man. The people who took part in these arguments were called *philosophers* (Greek for "lovers of truth"). One philosopher thought very deeply about the world around him and asked himself this question:

"If I cut up a piece of matter into smaller and smaller pieces, would I, in the end, get a piece so small that it could not be broken down any further?"

He came to the conclusion that there must be such small pieces or *particles*, the smallest possible parts of matter, which could not be cut any more. He thought that they were of many different shapes, and so small that they could not be seen. The materials of which our world is built, he said, are different, because they are built of different kinds of pieces, and in this way he explained why wood, for instance, is different from water. He called these particles *atoms*, because in Greek the word "atomos" means "that which cannot be cut."

This philosopher lived nearly 2500 years ago and his name was Democritus. His ideas were not all correct, of course, but he is regarded by many as the father of the atom, for he was the first man ever to have thought of it.

But in the times of Democritus scientists could not test ideas like that by experiment, and so the atom remained only a thought and was soon forgotten.

How Democritus imagined atoms to be made of different materials

Throughout the Middle Ages, the idea that matter is made up of atoms did not tempt philosophers to carry out experiments and find out more about them. They were concerned with other things. There were, however, *alchemists*,

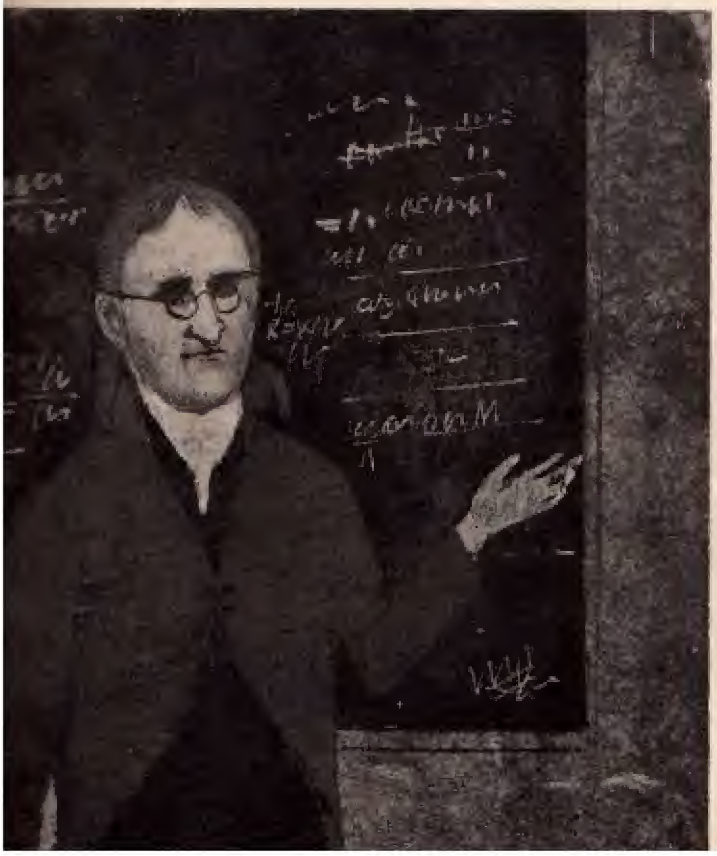
the first chemists, who searched mainly for a mysterious "philosopher's stone," a material that would turn lead into gold by magic. They carried on their search with the help of all kinds of tricks and hocus-pocus, and many kings and princes employed alchemists in the hope that they would make them very rich by discovering the secret of gold-making. Of course, they never discovered the secret because to change one kind of matter into another is a job for the modern scientist, and he can only do it with complicated machines. But the alchemists did build up a large store of knowledge about making chemicals.

Left: An alchemist's kitchen and some of the strange instruments used by alchemists. In trying to make gold they sought the help of the stars, as is shown by the chart at the bottom of the page

About two hundred years ago scientists began to make real progress in learning more about the nature of the world we live in. The alchemist turned into the chemist and the alchemist's kitchen became the *laboratory* where chemists work to discover the secrets of nature. There they found that all matter consists of a number of chemical *elements* such as iron and carbon, oxygen and sodium; and that many things are combinations of these elements. Hydrogen was discovered to be the lightest of all elements—and soon there was a great practical invention based on that discovery: the balloon. For

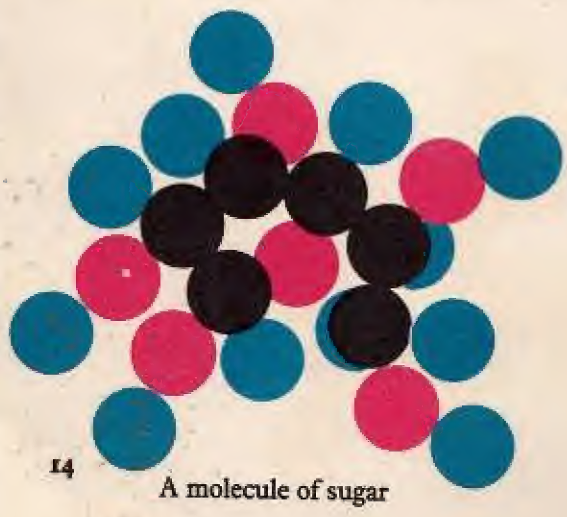
the first time, men were able to rise from the earth and fly; an achievement which almost everyone had believed to be impossible!

So many new discoveries were made at that time that it was necessary to find an overall idea to explain what matter is. It was an English chemist, John Dalton, who did the explaining early in the last century. He said that all matter, living or dead, is made up of atoms and that each element has its own special kind of atoms.

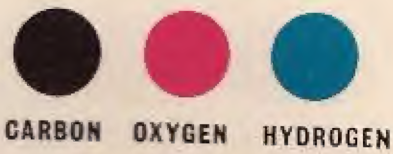


Dalton's chart of the elements

These atoms, Dalton said, like to stick together in clusters or *molecules*; such a molecule may consist of many or few atoms of the same element or of different elements. For instance, atoms of oxygen and hydrogen combine to form molecules of water. Much of our food consists of combinations of atoms called carbohydrates—for instance, sugar and starch. Oxygen, nitrogen and some other gases form the molecules of the air we breathe. The way in which the atoms of the 100 or so different elements form these molecules is so varied that they make up the whole world we live in, with all its innumerable kinds of matter—animal, mineral or vegetable.



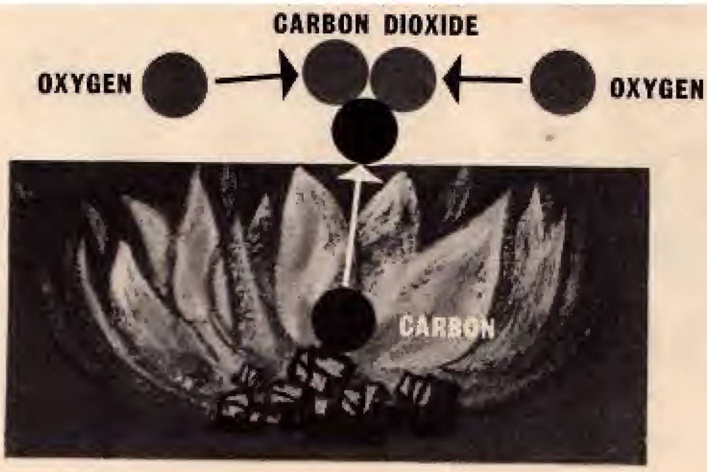
A molecule of sugar



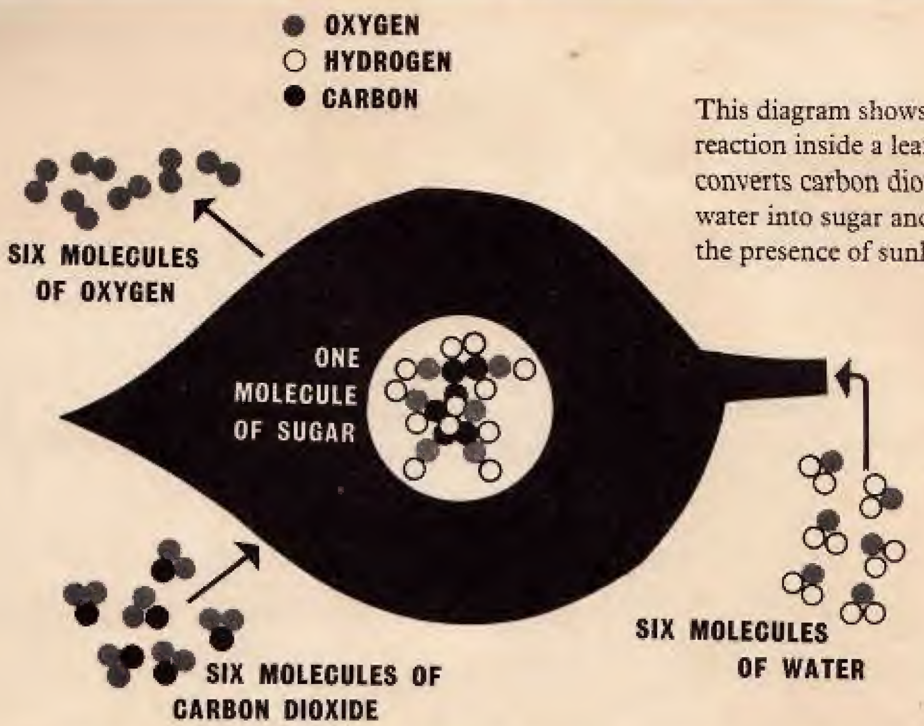
A molecule of octane

A molecule of banana oil

A molecule of aspirin



Nature and man can change these combinations of atoms; in fact, life is nothing but an endless series of such changes called *chemical reactions*. Molecules are broken up, and the atoms of which they consist join up with others in some other way. This happens when we burn coal. As you can see in this picture, each atom of carbon in the coal joins up with two atoms of oxygen from the air. This cluster of three atoms forms one molecule of carbon dioxide, a gas. While this happens, a great deal of heat is given off. Chemical reactions are going on all the time: when plants produce their sugar and starch, or when gasoline and air explode to give the force that drives an automobile, when we digest our food or take a



This diagram shows the chemical reaction inside a leaf when it converts carbon dioxide and water into sugar and oxygen in the presence of sunlight

snapshot with our camera. All the time atoms are changing partners to form new molecules.

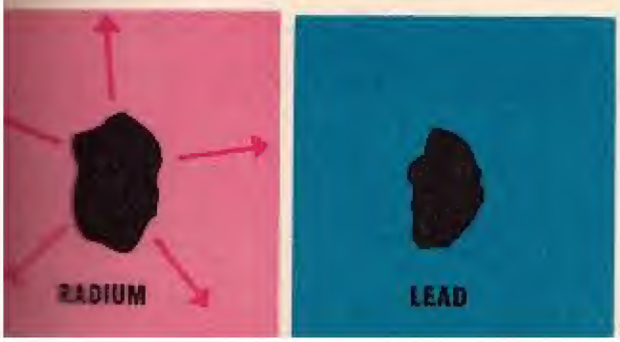
When Dalton worked out his *theory*, as we call such an explanation, he believed that Democritus had been right and that the atom was, in fact, the smallest part of an element which could not be broken up any further. For nearly a hundred years, that theory remained the foundation of all thinking and experimenting in science. But then, in 1898, something happened which caused a revolution in the whole world of science.

A Polish-born woman scientist, Marie Curie, and her French husband, Pierre, discovered a new element in their laboratory near Paris. They found it by boiling down a whole ton of *pitchblende*, a mineral ore containing the metal, uranium. What they found was a strange whitish salt, which gave off a faint, blue light in the dark. This light was caused by a constant stream of rays shot out by the salt. The Curies called it *radiation*, and gave their new element the name of *radium*,

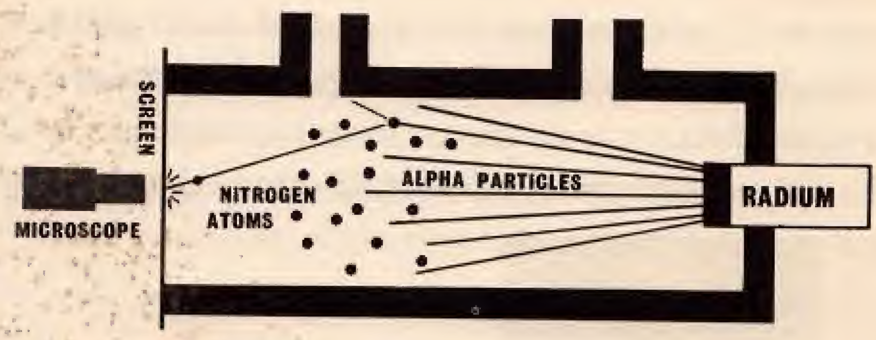
the "shining element." There were rays of three different kinds which were called *alpha, beta* and *gamma rays*, after the first three letters of the Greek alphabet. The first two kinds were small particles, that is, tiny pieces of matter. The gamma rays which do not consist of particles but are invisible waves (similar to radio and television waves), were found to be the most powerful and dangerous to man because they can pass

right through the human body.

Why was this discovery such a sensation? It proved that the atom was not the solid, unchangeable particle of matter which it was thought to be: it was able to break up. Small pieces of radium atoms shoot out in the form of radiation, leaving behind a different element which eventually becomes lead.

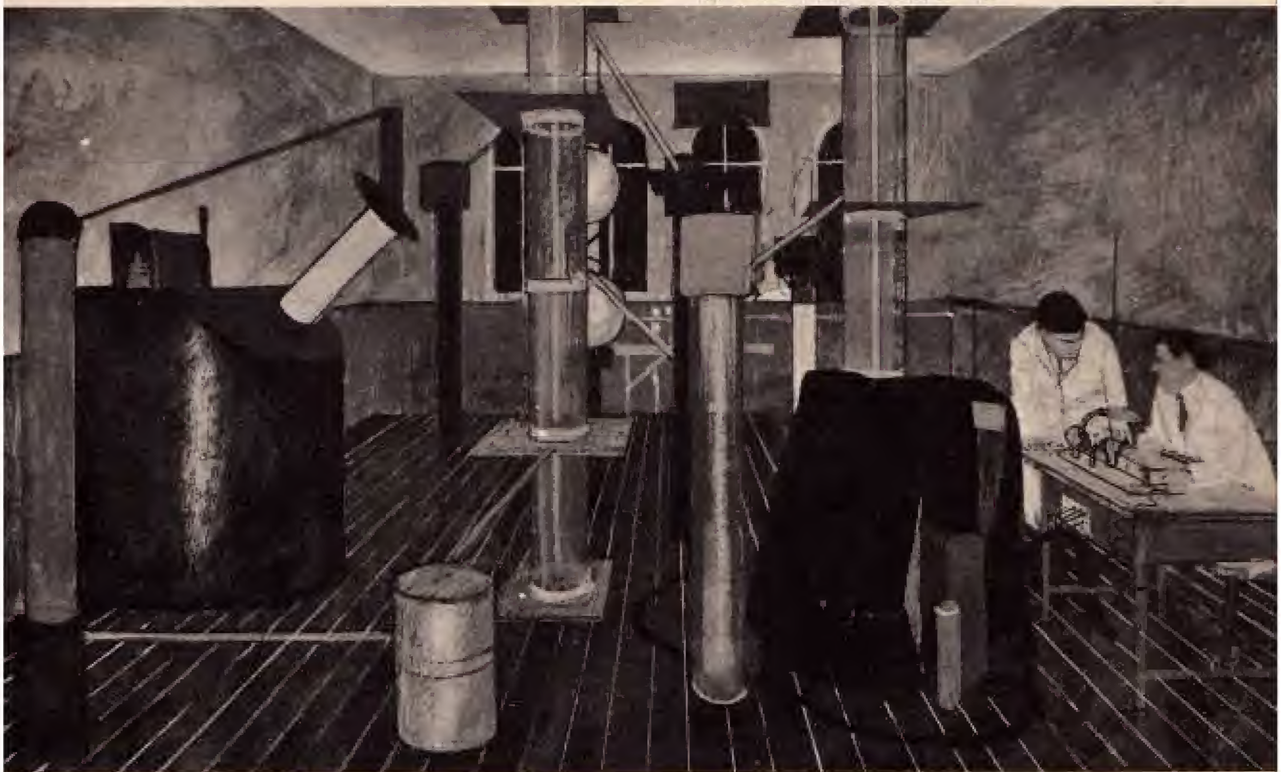


The Curies' discovery was the starting point for an entirely new kind of research all over the world. If the atom was not the smallest piece of matter, the smallest particle, what was it really? What did it look like? Unfortunately the scientists could never hope to *see* an atom, not even under the most powerful microscope. They had to go to work like detectives on the track of a criminal who by some magic had made himself invisible: he left clues here and there, and from what he had done one might get an idea of how he would behave under certain conditions. In this way, little by little, the scientific detectives were able to piece together a picture of the invisible atom. For instance, by shooting alpha particles at certain atoms and observing the effects through a microscope, it was possible to discover a great deal about the character of the atom, even though the atom itself could not be seen.



This is how Lord Rutherford studied the behavior of alpha particles

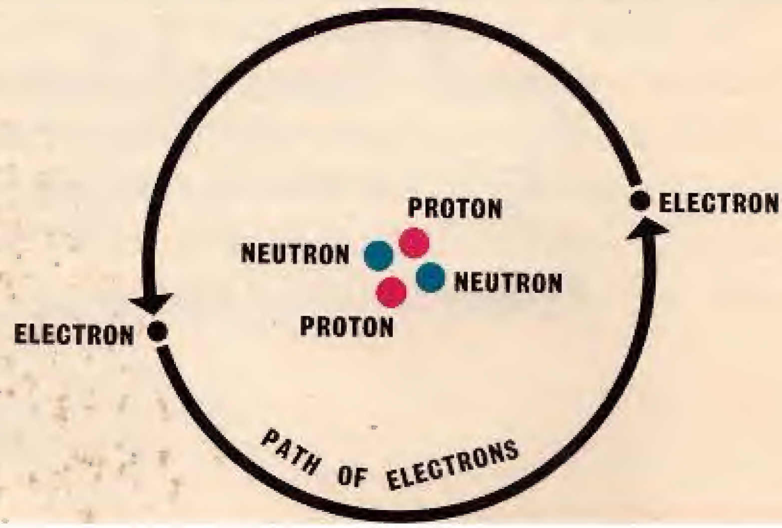
This was the apparatus used by Sir John Cockcroft, the English physicist, in a famous experiment in 1932, in which he succeeded in changing one light element into another

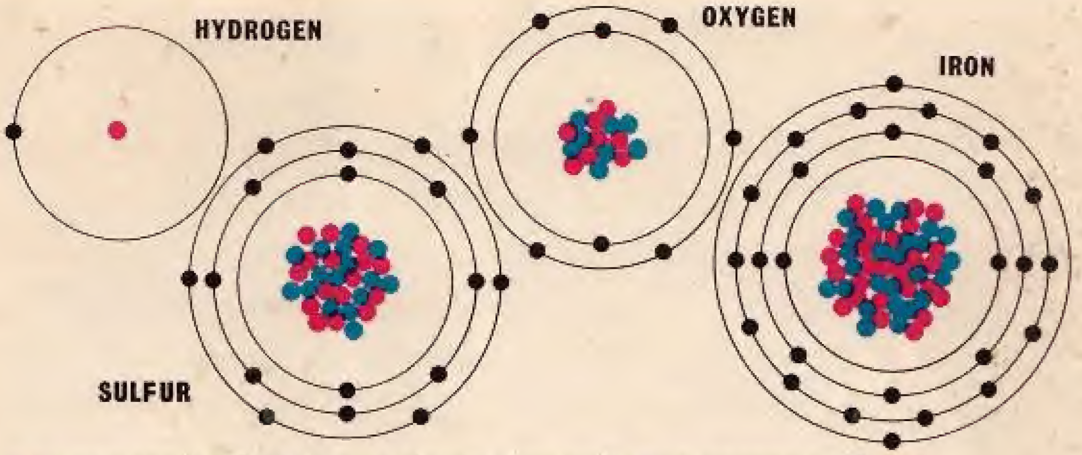


It is mainly to Sir Ernest (later Lord) Rutherford, a New Zealander who worked in Canada and England, whom we owe our picture of the atom. He drew its first outlines together with a Danish scientist, Niels Bohr, over fifty years ago, and later other scientists added new features to it. But even today, we are still not quite sure whether it is correct.

However, what we now believe is this: the atom consists of a very small core called the *nucleus* (Latin for kernel)—which contains almost the whole mass of the atom—and of a number of small particles called *electrons*, which are carriers of electricity but have very little mass. The electrons move at great speeds around the nucleus, in various paths—like tiny planets around a miniature sun. The nucleus, too, has an electric charge, but a different one from the electrons. Thus the charge of the electrons and that of the nucleus cancel each other out.

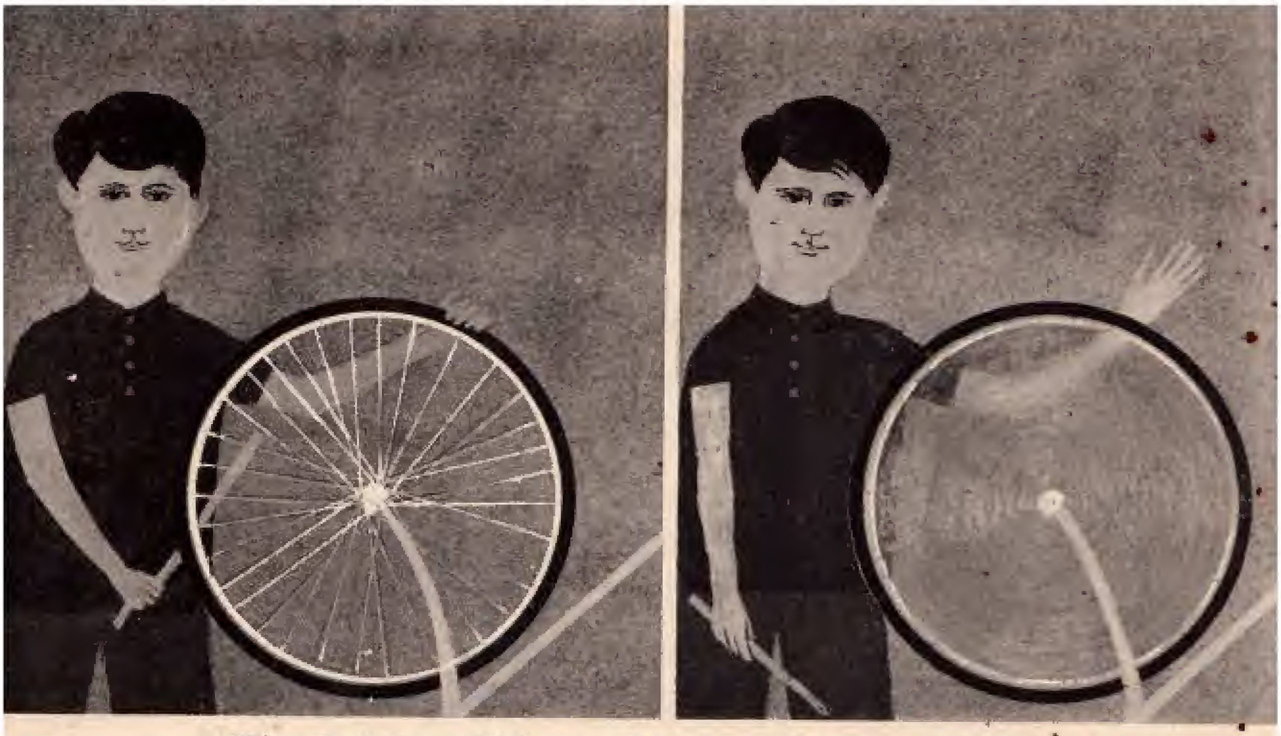
What is the nucleus made of? It is by no means one solid little lump of matter. It contains *protons*, which carry the electric charge, and usually a number of *neutrons*, which have roughly the same weight, or mass, as the protons but have no electric charge. Each element has a different number of protons, and that is why elements are different. Hydrogen, as



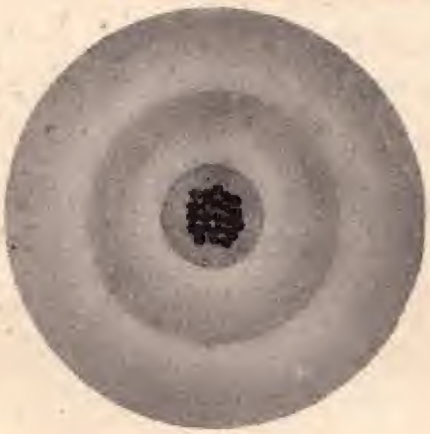


you can see in the picture above, has only one proton and one electron whirling around it. Helium, a gas, has two protons and two neutrons. Sulfur has 16 protons, iron has 26, and uranium, the heaviest element, has 92. You will notice that in the more complicated atoms the electrons are arranged in several layers. There are, as a rule, as many electrons rotating around the nucleus as there are protons in it. And the matter of which the protons consist is exactly the same for each element—not of a different kind as Dalton believed.

Can we get an idea of the size of the atom and its nucleus? If we could enlarge the *whole* atom a million times it would be about as big as a pinhead. But if we wanted to see the nucleus we would have to enlarge the whole atom twenty thousand million times! It would then be as big as a railway car—but the nucleus would be just about big enough to be seen. There would be vast empty spaces between the nucleus and its electrons—in fact the greatest part of all matter is empty space.

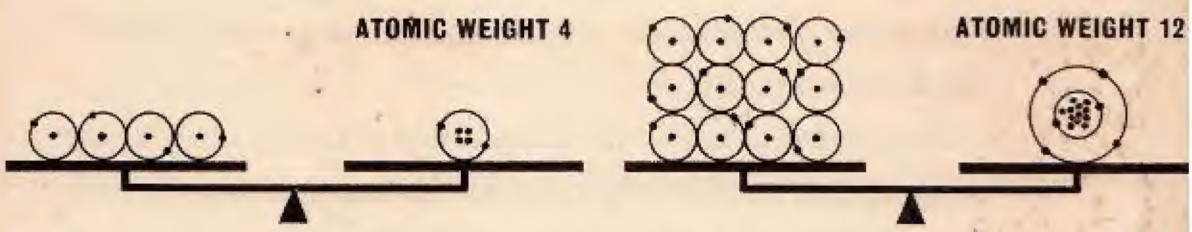


The electrons whirl around their nucleus so quickly that they form a solid wall. If you find this difficult to understand, try to think of the spokes of a bicycle wheel when the wheel is turning. In this way, each layer of electrons forms a shell—and the more complicated atoms are rather like onions in structure. Electrons are very light—1800 of them would be as heavy as one proton.

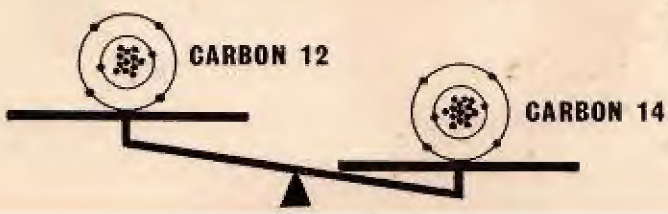


Normally hydrogen has only one proton and is the lightest of all elements. Since protons and neutrons are roughly the same weight, the total number of both kinds of particles inside

the nucleus of an atom tells you what its weight is compared to the weight of the hydrogen atom.

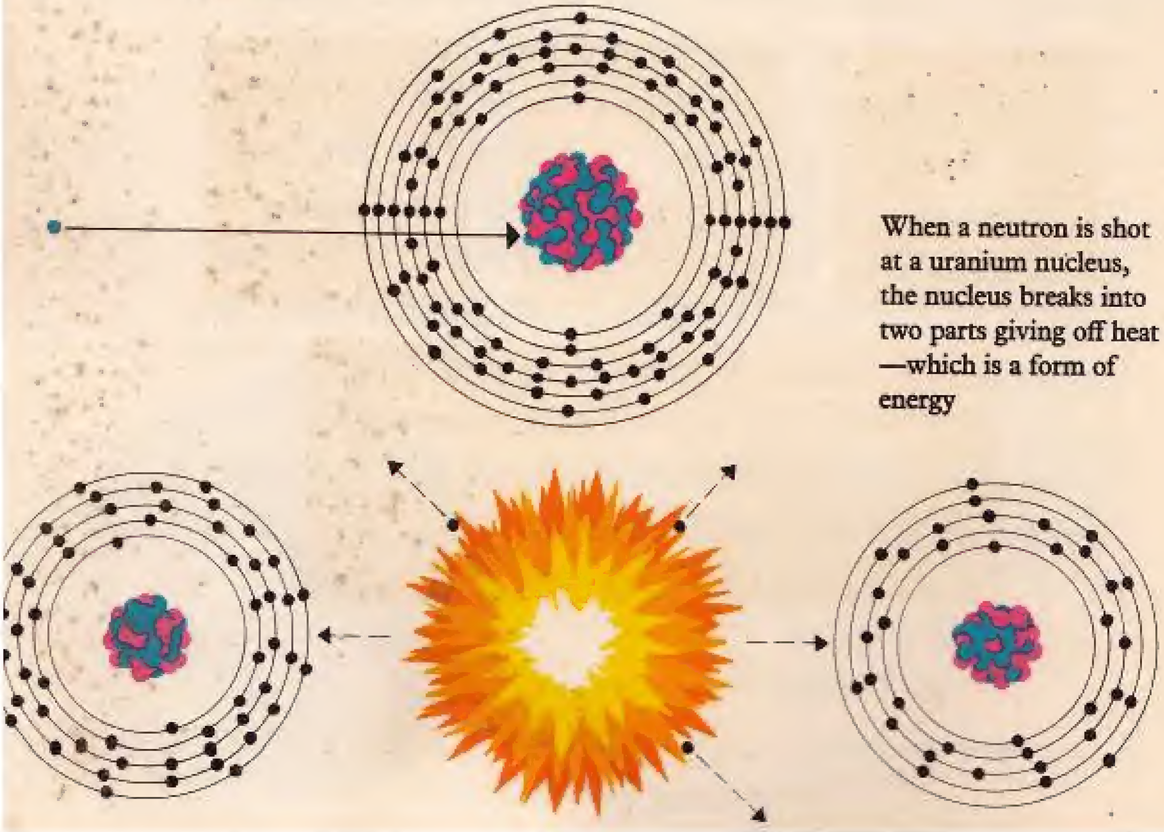


But although most hydrogen nuclei (plural of nucleus) have only one proton, a few have one proton and one neutron, and some can even be found with two neutrons. The number of protons in the nucleus of any atom tells us the name of the element, but for a full description we must also know the total number of both protons and neutrons in the nucleus. Carbon, for instance, always has 6 protons, or it would not be carbon. The usual kind of carbon also has 6 neutrons which makes a total of 12 particles, and therefore we say that it has an *atomic weight* of 12. But there is another kind which has 6 protons and 8 neutrons. This means that there are 14 particles in the nucleus and this kind of carbon is called carbon 14. It is a heavier kind of carbon. Most elements occur in several kinds, some heavier and some lighter; those which are different from the usual kinds are called *isotopes*.



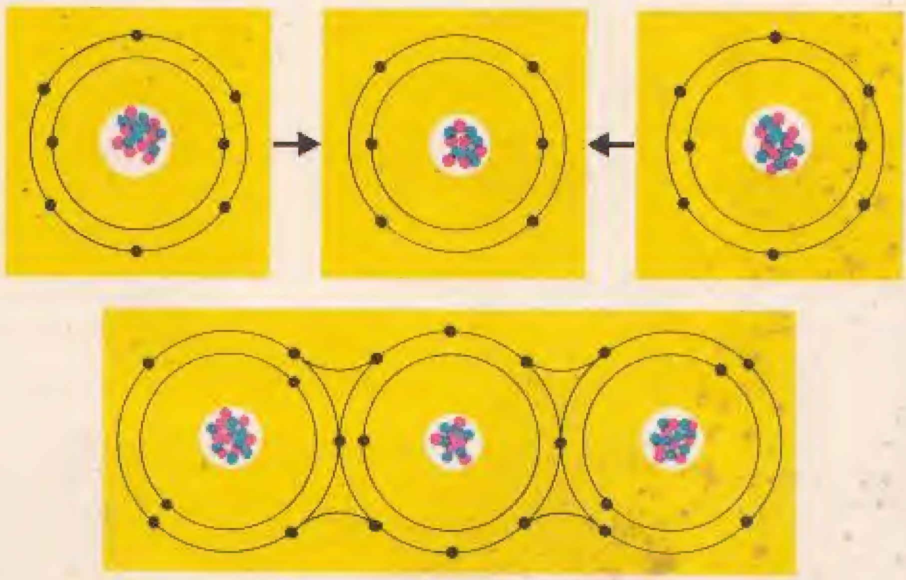
We have seen that only the number of protons inside the nucleus makes one element different from another. If we add protons to the nucleus of an atom or reduce their number, we change one element into another, and thus we succeed where the alchemist failed.

If a neutron is shot at the nucleus of a uranium atom, it may break up into two or more parts. In this way new elements are formed. But not all the neutrons of the uranium atom stick to either one or the other of the newly formed atoms; two or three escape on their own. The splitting of an atom is called *fission*.

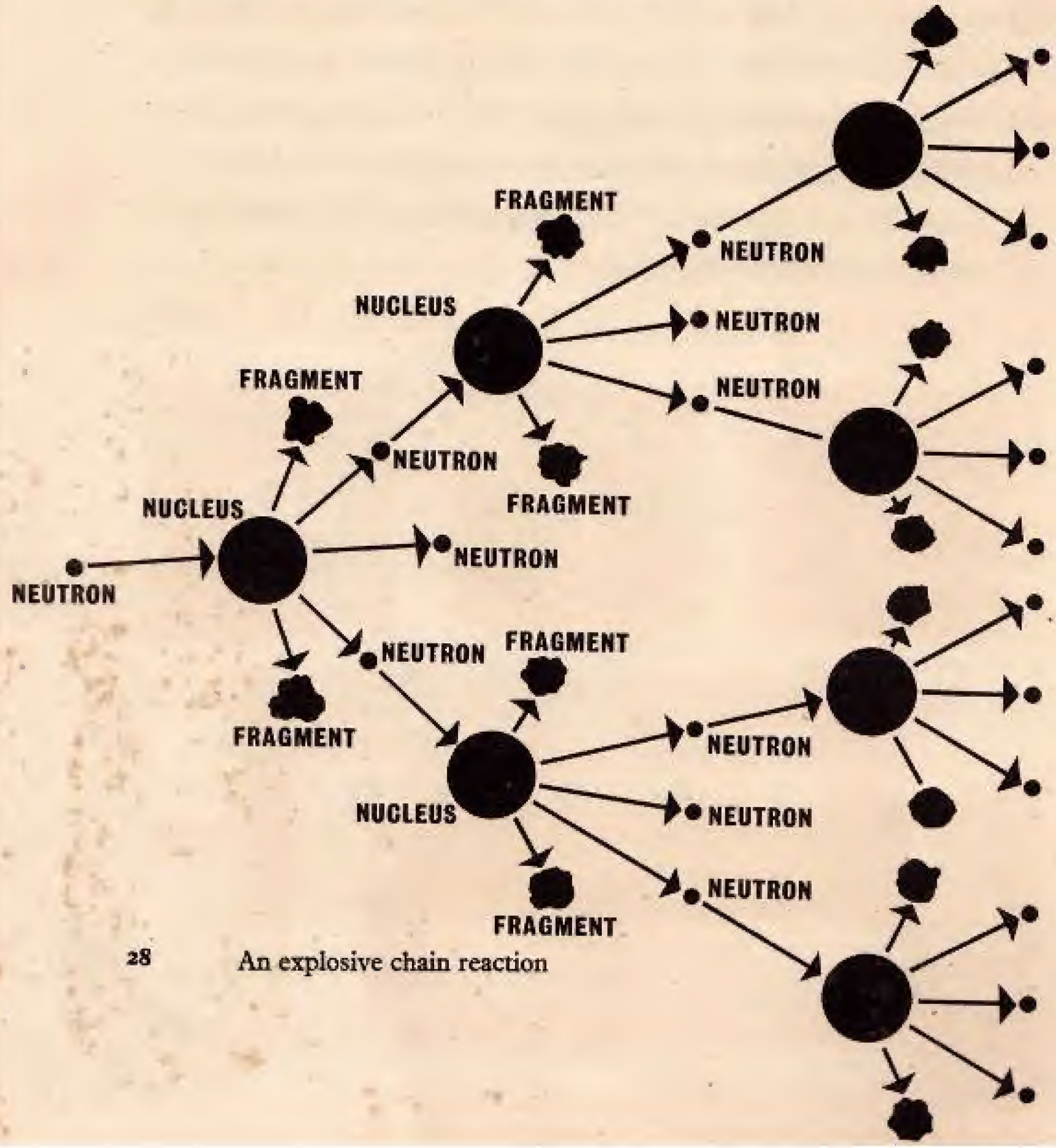


When a neutron is shot at a uranium nucleus, the nucleus breaks into two parts giving off heat —which is a form of energy

A process like this, in which the nucleus of an atom is changed, is called a *nuclear reaction*. It differs from a chemical reaction. As you can see in this picture, in a chemical reaction atoms may join up and some of their electrons may share the same path. But their nuclei remain untouched and unchanged. In a nuclear reaction, on the other hand, the nuclei themselves are changed. In this process a great deal of heat is given off, as in some chemical reactions such as burning. But the heat obtained from a nuclear reaction is a million times greater than that from a chemical reaction.



What happens to the two or three neutrons which escape at great speed when such an atom breaks up? They continue on their journey until they escape altogether or hit nuclei of surrounding atoms. These atoms can also break up, in the

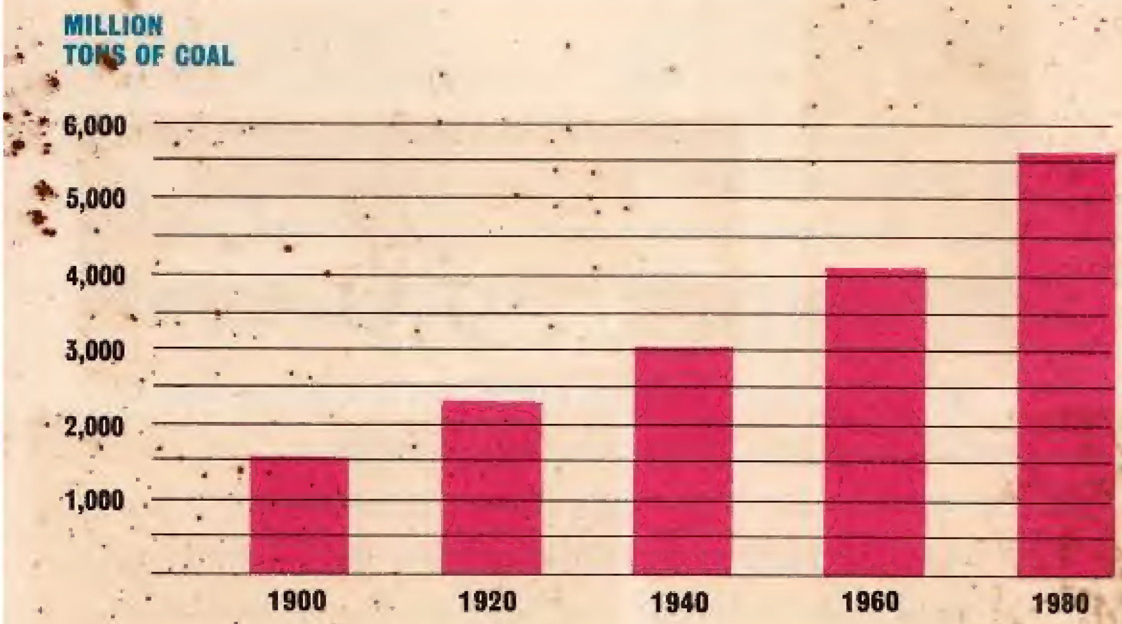


An explosive chain reaction




ENERGY

Whenever we wish to make anything, from pins to airplanes, or transport it, we need energy. No work can be done without energy. In the beginning man had only the energy of his own muscles. Then he learned to make use of the energy of animals, of wind and water, of coal and oil. Nowadays ordinary people live in greater comfort than princes did in the past and this is because man has been developing better, cheaper and more plentiful sources of energy.

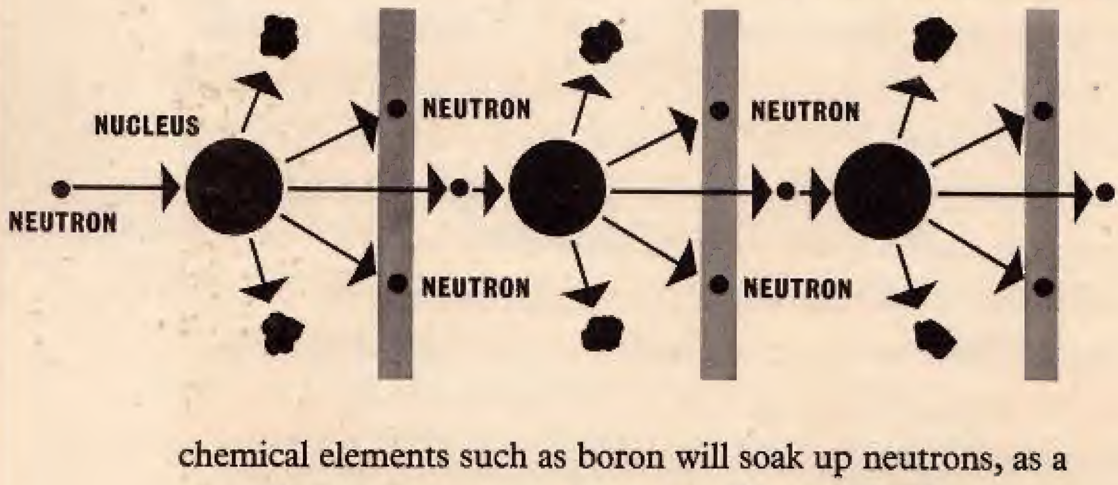


This diagram shows how much energy in the world was produced from coal and oil at the beginning of this century, and how this amount has gone up ever since. You can also see how the amount of energy we need is bound to go up in future years. You must remember that every time a new machine is installed in a factory, every time a new car or truck takes the road, more energy is required; also the population of the world is increasing all the time and so more energy still will be needed. But it would be very difficult, if not impossible, to get all that extra energy from coal and oil and this is where atomic energy comes in. It will provide most of the extra energy we are likely to need for many, many years.

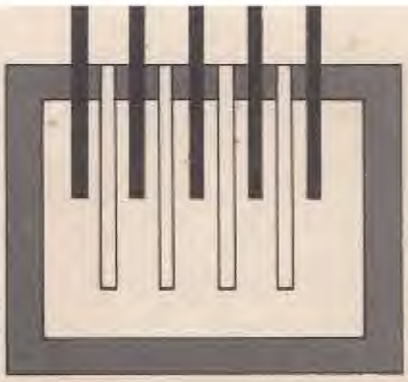
Normally an atomic explosion cannot be made to do any useful work. The only way to make it useful is to slow down the nuclear reaction, and turn it into electrical energy.

As we have seen, it is the stray neutrons which are the key to the chain reaction and if we manage to reduce their speed, the nuclear reaction will be greatly slowed down.

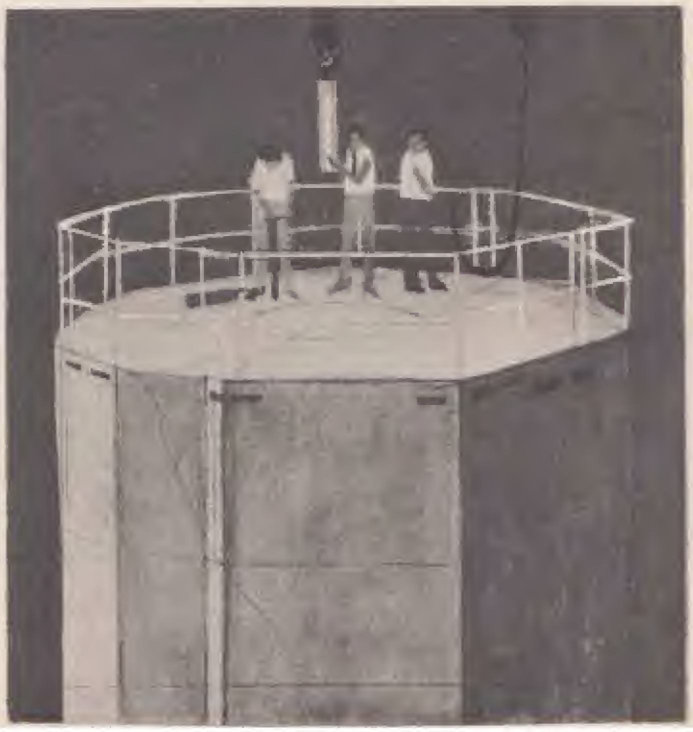
This can be done in what is called a *nuclear reactor*, which is nothing more than a kind of furnace, a container with thick concrete walls in which a nuclear reaction takes place. If we surround the uranium rods in which this reaction happens with bricks of pure carbon—the graphite of which our pencil leads are made—the neutrons will bounce off the carbon atoms like billiard balls, and slow down. It has also been found that some



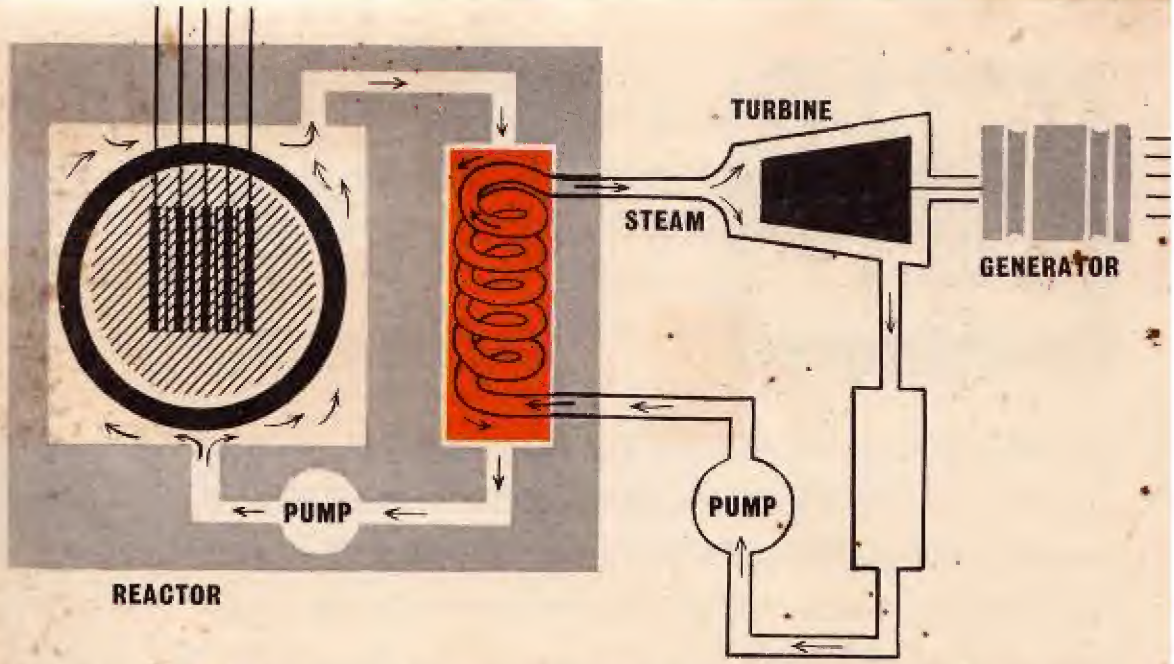
chemical elements such as boron will soak up neutrons, as a piece of blotting paper soaks up ink. If rods of such an

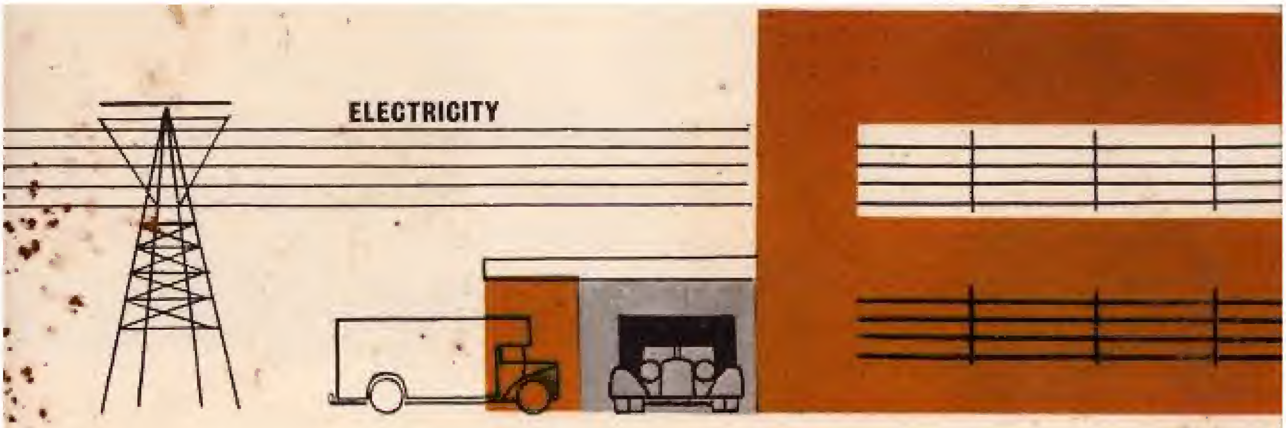
element, called *control rods*, are lowered into the reactor, they mop up some of the surplus neutrons and slow down the reaction. If they are raised a little, they will soak up fewer neutrons, more atoms will split and the reactor will produce more heat. They keep the chain reaction on a constant level. Compare the diagram on page 32 with the one of the chain reaction on page 28. This is called a controlled chain reaction.



The loading platform of a nuclear reactor



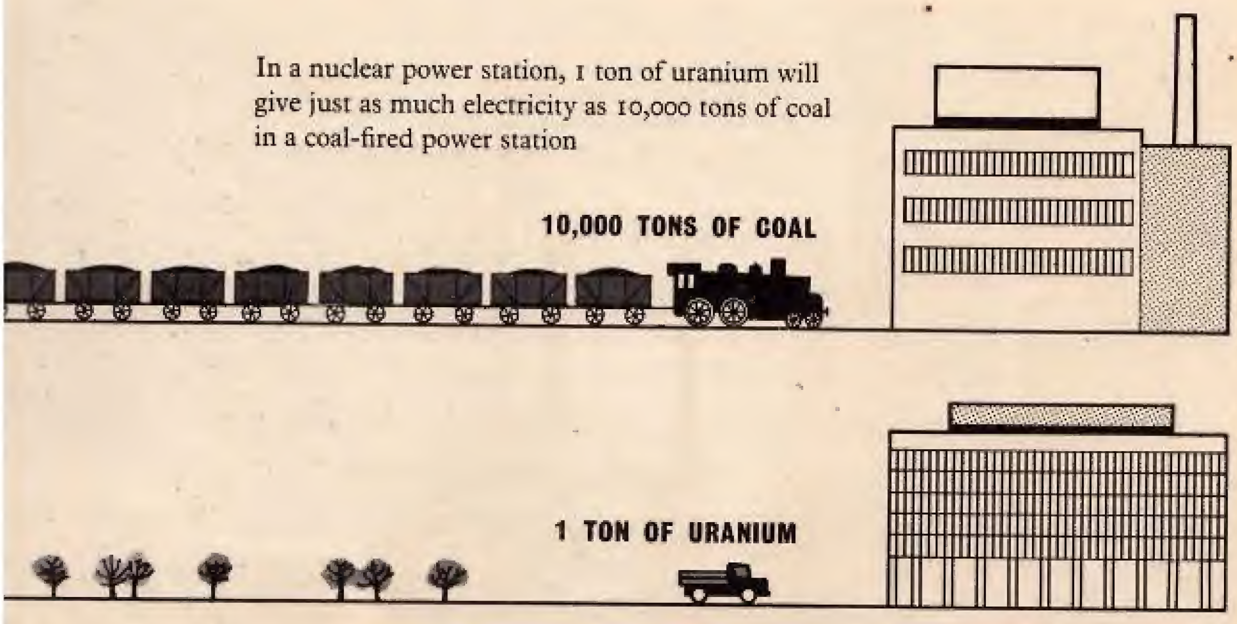
In this way it has been possible to tame the great force of the splitting nuclei and to put it to work for us. In a nuclear power station, the heat produced can be made to heat a liquid or a gas which circulates in and out of the reactor. This hot gas or liquid also flows through a *heat exchanger*, where it turns water into steam. The steam goes into ordinary steam turbines which drive electric generators, and these produce electric current for our homes, factories and trains.



A nuclear power station

It is a roundabout way of making the atom give us electric current, but for many years to come this will be the usual way of doing it until the scientists have found a simpler and cheaper one. The one thing that is cheap about nuclear electricity is the fuel; an enormous lot of energy comes from very little uranium.

In a nuclear power station, 1 ton of uranium will give just as much electricity as 10,000 tons of coal in a coal-fired power station



But compared to a gasoline engine, a nuclear reactor is extremely heavy (and dangerous); and that is one of the reasons why there will be no atomic automobiles for a while yet.

The *Savannah*, the first American nuclear-powered ship

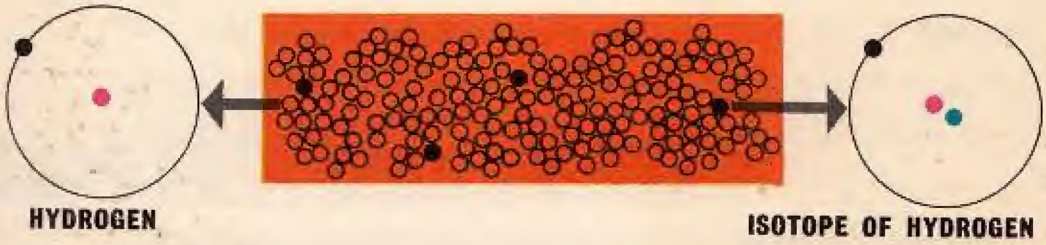
Nor will there be any nuclear airliners. But there are already some atom-driven ships—America has quite a few nuclear submarines and a merchant ship; Russia has submarines and a nuclear icebreaker—because at sea, bulk and weight do not play such an important part as on the road and in the air. Nuclear railway engines are not very practical; a better use of atomic power is to have electric railways supplied by nuclear power stations.

However, the space-travel engineers are working on atomic rockets. Some scientists believe that our only chance to get to some other planet is by nuclear rocket, because it would need comparatively little fuel.

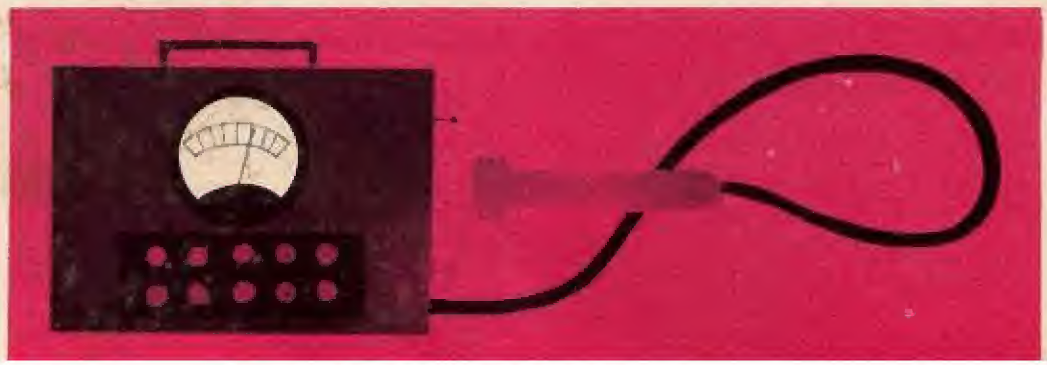
Russia's nuclear-powered ice-breaker, *Lenin*

ISOTOPES

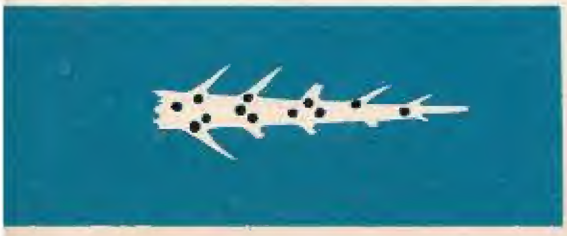
Most elements, as we have seen, contain a few atoms which are slightly different from the rest; they are heavier or lighter. Water, for instance, consists of two atoms of hydrogen with one atom of oxygen, as we know; but a small number of the hydrogen atoms are heavier because they have an extra neutron or two in their nuclei. These odd atoms, which are different from the rest, are called isotopes. Most isotopes have too many neutrons in their nuclei; we might say they have atomic

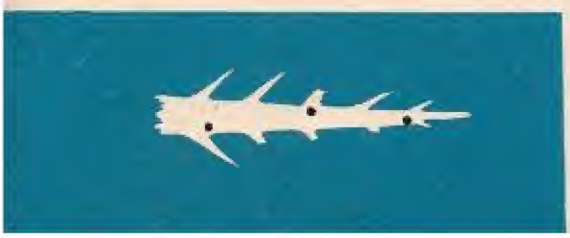


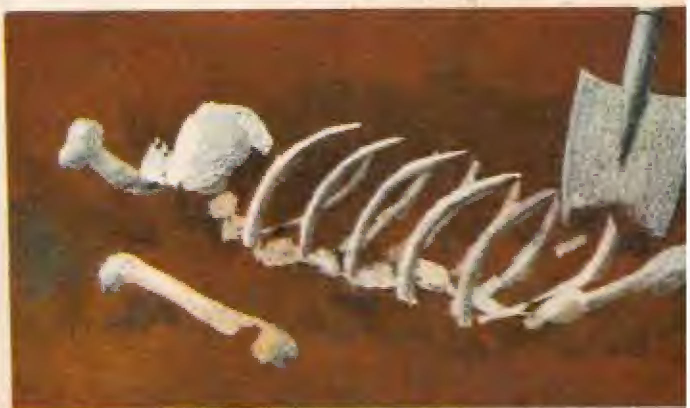
indigestion. They get rid of this by shooting out particles and rays and changing into other kinds of atoms. This behavior is called *radioactivity*, and radium is an example of this. The particles and waves can be detected by an instrument called a *Geiger counter*.

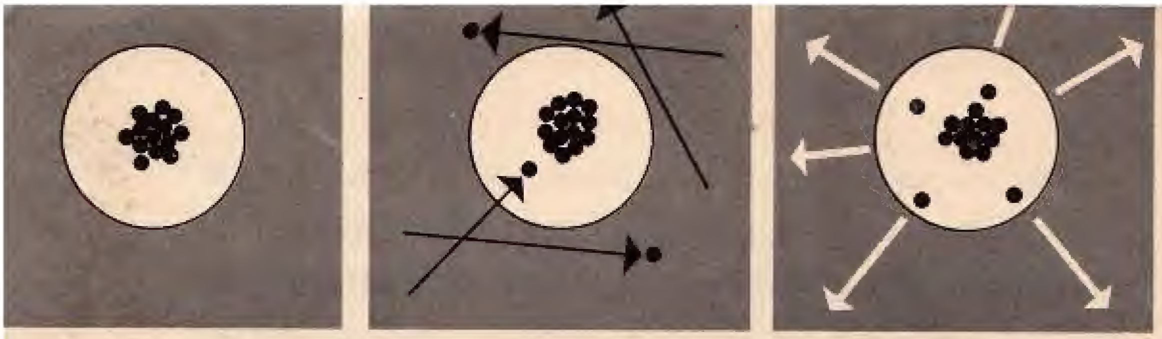


As we saw on page 25, carbon, too, has its isotope, known as carbon 14 because it has 14 particles in its nucleus, instead of 12 as in ordinary carbon. All living things take in carbon and, with it, a few radioactive atoms of carbon 14. When a plant or an animal dies, it stops taking in any more carbon. The carbon 14 atoms already in the body break up, as all radioactive atoms do, and over the years there will be fewer and fewer carbon 14 atoms present. After 5,600 years only half the original carbon 14 atoms will be left. After many thousands of years nearly all the carbon 14 atoms will have disappeared. By measuring with a Geiger counter how many remain, it is possible to find out the age of very old objects and skeletons.







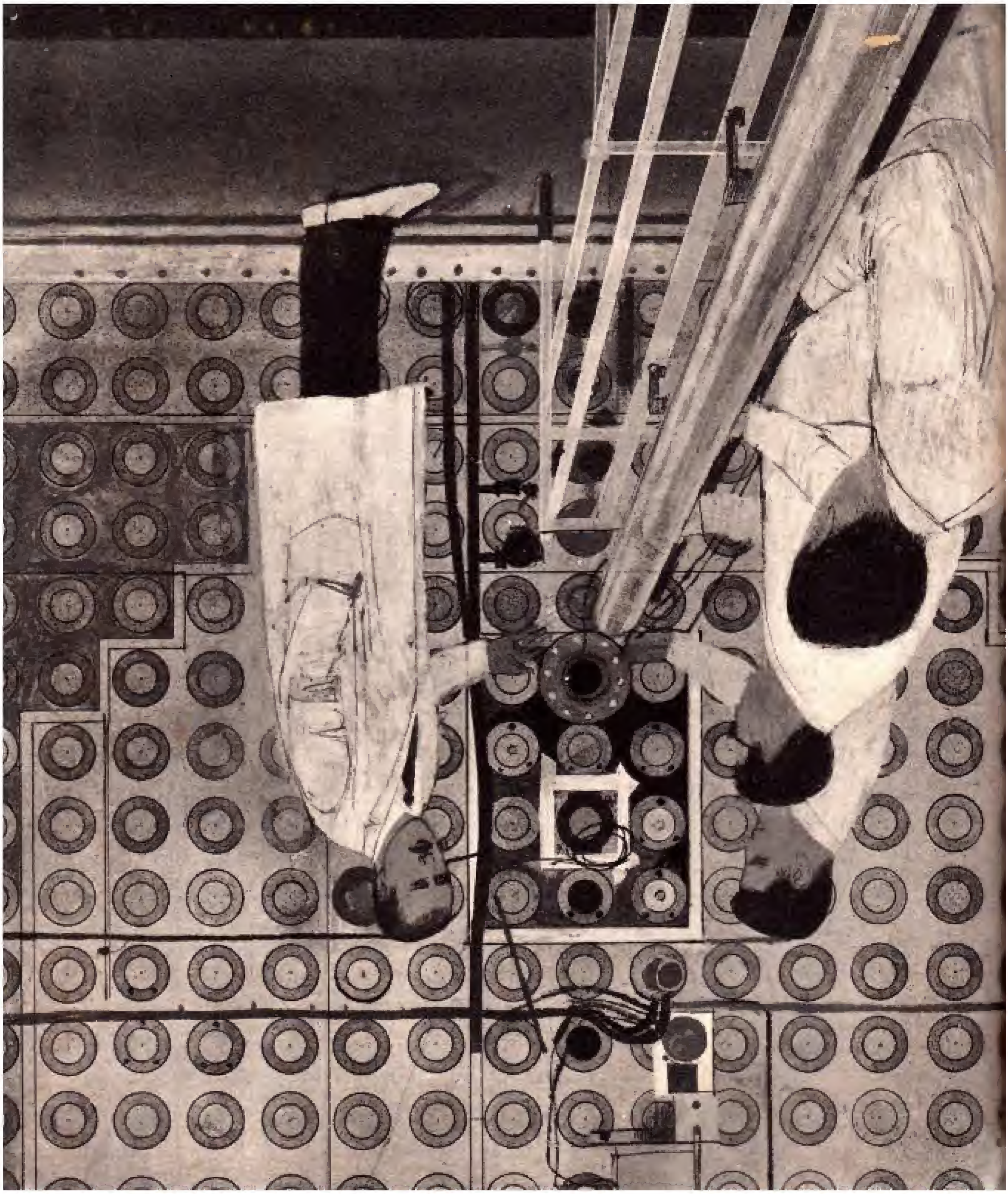


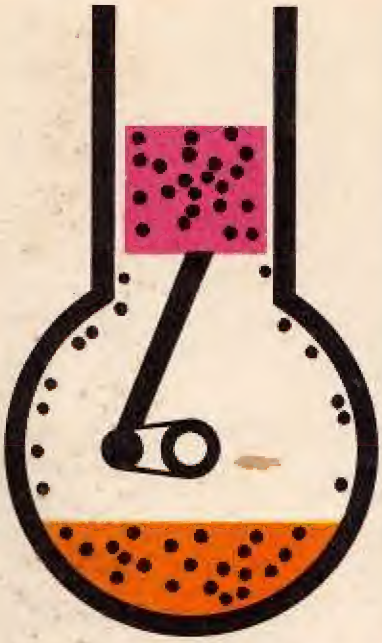
Now there is a way of turning atoms of most elements into radioactive isotopes by putting them into a nuclear reactor and pelting them with neutrons. As you can see in the picture, most atoms will absorb an extra neutron and so become radioactive isotopes, or *radioisotopes*, as the scientists call them.

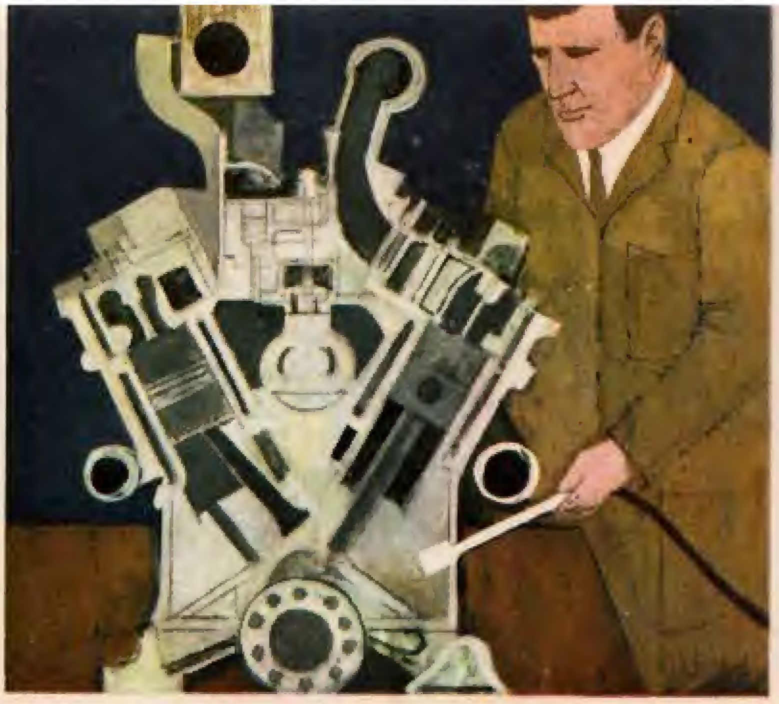
Because their radioactivity can be detected even in very small amounts, these radioisotopes can be used for many purposes in medicine and industry.

Radioisotopes have to be very carefully packed to prevent dangerous radiation from escaping

Right: A tube containing an element is put inside a reactor to be bombarded by neutrons; in this way it is turned into a radioactive isotope



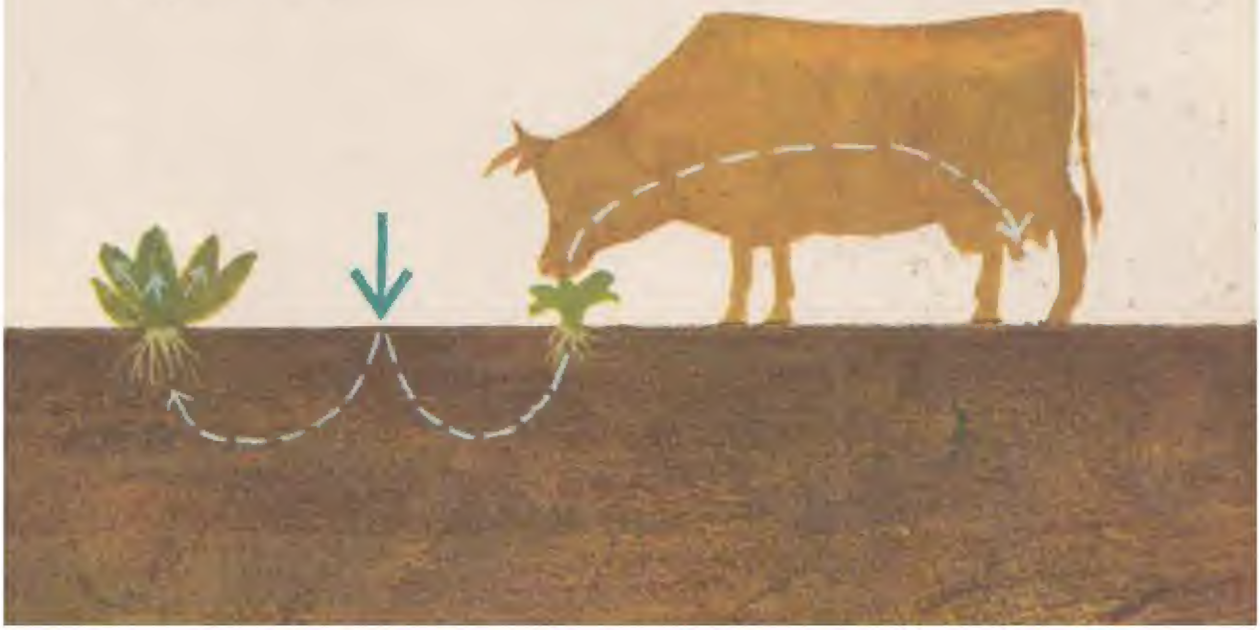




Radioisotopes can help us to find out how certain machine parts wear. If an engineer wanted to see how well a certain kind of oil lubricates an engine, he could make the piston radioactive by putting it in an atomic reactor. As the engine was running, small bits of steel would be rubbed off and washed down by the oil which would now be slightly radioactive. This radioactivity in the oil could then be measured by a Geiger counter, which would tell the engineer how much steel had worn off. By testing a number of different oils in this way, the engineer would be able to judge which oil was best in preventing wear. This would have been almost impossible to find out in any other way.

It is possible to find a leak in a pipe by adding radioisotopes to the liquid and tracing them with a Geiger counter as they escape to the outside of the pipe. But radioisotopes have many more uses in industry, such as testing materials for faults and even thickness, in making steel or paper for instance in an automatic factory.

When farmers use fertilizers for better crops they can never be quite sure how much of the fertilizers are used by the plants. By adding radioisotopes to the fertilizers it is possible to trace them right through the plant and find out how much is taken up and how long it takes to be used up. If the plant is eaten by an animal a Geiger counter will trace the radioisotopes right through the animal's body. In this way scientists can study the behavior of plants and animals, which they could not do in any other way.



You have read that gamma rays can kill living things and this fact too has been turned to good use. Many goods, especially medical supplies, must be *sterilized,* that is, made free from germs. If they are sterilized before they are put in packages, they may pick up further germs before the packages are sealed. But now it is possible to put such goods in containers, seal them, and then put them near a radioactive isotope. The gamma rays from the isotope will kill any germs inside the container and, since it is airtight, it will remain free from germs until it is used. This is especially important when medical supplies have to be used in places where there is no means of sterilizing them. This process of treating goods with rays is called *irradiation.*

Certain foodstuffs, for instance frozen eggs, can be irradiated if the presence of disease-carrying germs is suspected.

But it is in medicine that perhaps the most important use of radioisotopes lies. If a small amount of radioisotopes is injected into the bloodstream, a Geiger counter can trace its path exactly from outside the body. In this way it is possible for doctors to study the bloodstream and recognize certain diseases where all other means may fail.

The workings of many organs of the human body can be studied in this way.

Radioisotopes can be used not only for detecting diseases, but also for curing them. Sometimes an injection or a capsule containing a radioisotope, placed near the seat of a disease, will heal the patient.

Where larger doses of radiation are needed a so-called *Cobalt "bomb"* may be used. This is a lead container with a tiny piece of cobalt radioisotope inside. Its radiation is used to treat certain forms of cancer.

It is only a few years since we began to understand the atom and its energy. Already it has proved itself capable of causing destruction the world has never before witnessed. But it also contains the promise of much good for all of us—to cure disease; to improve crops and so provide more food for all those millions of people in the world who are still underfed; and to give us more cheap energy so that poverty may become a thing of the past.

The atom, like every force used by man, can do good or evil. How it shall be used depends on us.

Some of the new words you have read in this book.

Alchemist. Forerunner of the modern chemist.

Alpha rays. Particles sent out by "unstable" elements such as radium and radioactive isotopes. They are helium atoms without their electrons.

Atom. The smallest part of an element that can exist.

Atomic weight. The weight of the atom of an element compared to the weight of the atom of hydrogen (atomic weight, 1).

Beta rays. Stream of fast-moving electrons.

Chain reaction. The process by which energy is produced in a nuclear reactor.

Chemical Reaction. An action in which chemical elements change their partners.

Cobalt "bomb". A lead box containing a piece of radioactive cobalt.

Control rods. Rods of boron which are used to start and stop an atomic reaction.

Electron. Particle which circles around the nucleus of an atom. It carries an electric charge.

Element. One of the basic kinds of matter of which the universe is built.

Fission. The breaking-up of atomic nuclei into two or more parts.

Gamma rays. Electromagnetic waves like those which transmit sunlight and radio signals, but of much shorter wavelengths.

Geiger counter. Instrument for detecting radioactivity.

Heat exchanger. Boiler in which the hot liquid or gas from the reactor gives up its heat to water and so makes steam for use.

Irradiation. Bombardment with rays or particles.

Isotope. A variety of an element, with the same chemical properties but different weight because there are more, or fewer, neutrons in the nuclei.

Laboratory. A room or building in which scientists carry out experiments.

Matter. Any substance—solid, liquid, or gas—which is either found in nature or made by man.

Molecule. Group of atoms from one or more elements.

Neutron. Particle to be found in the atomic nucleus. It has no electric charge.

Nuclear reaction. Any process by which atomic nuclei are changed; especially the process in which they are split, whereby energy is released.

Nuclear reactor. The "furnace" in which nuclear fission produces heat.

Nucleus. The kernel of an atom with the electrons circling around it.

Particle. Very small part; may be an atom or part of an atom.

Philosopher. A man who thinks and produces theories about, for example, how things came to exist.

Pitchblende. A rock rich in uranium and radium.

Proton. Particle to be found in the atomic nucleus. It carries an electric charge.

Radiation. A constant stream of particles or rays.

Radioactivity. The breaking up of atoms which produces radiation.

Radioisotope. "Unstable" isotope which decays while sending out particles—alpha rays, electrons or gamma rays.

Radium. Element which "radiates" parts of its atoms as solid particles and energy; it decays into lead.

Sterilize. Make free from germs.

Theory. An explanation of a set of happenings.

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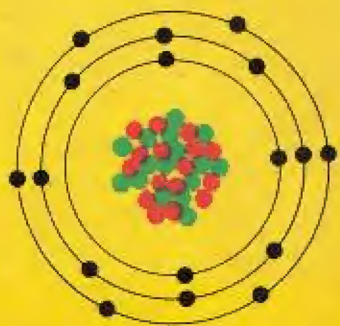

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